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ABSTRACT

Although tennis is becoming an increasingly popular game in the U.S., there exists little information on the advanced or competitive player. The purpose of this monograph is to give a nontechnical presentation of the research findings relative to the competitive tennis player. It is hoped that some of this information will encourage further investigation by interested readers. The monograph contains chapters on sociological and psychological aspects, physical and physiological characteristics, the mechanics of stroke production, organization and administration for interschool competition, and the need for additional research. It includes appendixes on the center of percussion and on the rules and regulations to govern intercollegiate dual match competition. (PB)

WHAT RESEARCH TELLS THE COACH ABOUT

TENNIS

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WHAT RESEARCH TELLS THE COACH SERIES

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FOREWORD

This is the seventh in a series of booklets titled *What Research Tells the Coach* about a particular sport, being prepared under the direct supervision of the American Alliance for Health, Physical Education, and Recreation. The purpose of these booklets is to make available to coaches pertinent research findings with interpretations for practical application and to compile a rather extensive list of research references about a specific sport.

Marvin R. Gray, professor of physical education at Ball State University, Muncie, Indiana, the author of this pamphlet, has been a collegiate participant in and a coach of tennis. He has published several articles on tennis coaching and is particularly interested in the psychological makeup of competitive tennis players and the history of the sport. We are very fortunate in having secured his services in this capacity.

Dr. Gray has done an outstanding job in listing what the coach should know, what the researcher has discovered and what is known and not known about the area of tennis.

We are very pleased to endorse and introduce this publication to the tennis people of the United States and the world. We believe those who are interested in the various aspects of tennis will find this booklet of great benefit.

John M. Cooper
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PREFACE

After several decades of modest exposure, tennis is experiencing an unprecedented growth in popularity. The increase in numbers of players, facilities (especially indoor racket clubs) and general public interest within the last few years has been phenomenal.

Unfortunately, this new popularity has not been reflected in the amount of scientific information available on tennis. Much has been written about the game for the beginner; some attention has been given to the intermediate; but comparatively little information exists on the advanced or competitive player.

There are several reasons for this lack of data. First, tennis has not been as popular as some sports in most parts of the United States; it was frequently associated with the well to-do social classes and was criticized in some circles as an activity for "sissies." Second, researchers were sometimes thwarted in their efforts to conduct sound studies on the competitive player because of inadequate sample sizes, for tennis teams rarely number more than 10 players. To combat the problem partially, some investigators combined several individual sports into a study group; however, this may have influenced the findings relating to the tennis group. Finally, interscholastic high school competition for both men and women is of relatively recent origin in most parts of the country; consequently, there has not been the general interest in securing scientific information on the advanced player. In this regard, it should be pointed out that very little scientific information exists on the precollege-age competitive tennis player.

The purpose of this monograph is to give a nontechnical presentation of the research findings relative to the competitive tennis player. The terms "competitive player" and "advanced player" are used interchangeably to identify one who has competed at one or more of the following levels: interscholastic, intercollegiate or open tournament.

From time to time, the author has taken the liberty of presenting information based on empirical evidence. A careful attempt was made to note any lack of documentation when such offerings were presented. This was done with a certain amount of trepidation (since this publication contains the word "research" in its title), but with the hope that such information might cause further investigation by interested readers.

Finally, the writer wishes to thank all those who were helpful in the preparation of this booklet, particularly key personnel in the Ball State University library, his wife, Janice, and Kathleen V. Bair, who first fueled the spark.

1. SOCIOLOGICAL AND PSYCHOLOGICAL ASPECTS OF COMPETITIVE TENNIS PLAYERS

SOCIOLOGICAL CHARACTERISTICS

Probably because of its aristocratic heritage, tennis has generally been associated with individuals from well-to-do socioeconomic backgrounds (2, 3, 36). This was found to be generally true with male intercollegiate tennis players in one of the few comprehensive studies in this area. In an investigation in which the social origins and present social status of Life Pass Holders[1] at a western university were examined, it was found that:

1. When former athletes assessed the status of their fathers' occupations, tennis players' fathers were ranked second. Golf players' fathers came out first and wrestlers' fathers last. Twenty intercollegiate sports were represented.
2. A total of 13.3% of the tennis players' fathers had a blue collar occupation. Out of 10 sports represented, only crew athletes' fathers had a lower percentage, 10.4%. The highest percentage of blue collar occupations, 48.1%, was held by wrestlers' fathers.
3. About one-quarter (25.91%) of the tennis players' fathers had not completed high school. This ranking was third out of 10 sports, exceeded by crew and soccer. About half of the wrestling, baseball and football athletes' fathers had not completed high school (21).

The same study attempted to determine various aspects of social mobility by comparing the average occupational prestige scores of the athletes' first jobs

[1] To obtain a Life Pass, the athlete must have competed at the collegiate level for four years and earned at least three varsity letters. This study was based on the responses of 845 Pass Holders - an 83% return.

after college and their positions in the spring of 1968 with those of their fathers' main occupations. Interestingly, the greatest degree of social mobility was achieved by athletes whose parents had the lowest socioeconomic status. There was not much difference in the occupational status scores of the various groups of athletes, with tennis showing the least mobility of all sports when compared with their fathers' main jobs. This would tend to support the theory that tennis players come from a higher socioeconomic background.

Other findings (21) revealed that 40.72% of the tennis players held an advanced degree (fourth out of athletes representing 10 sports); gymnastics was highest, 61.75% and football was lowest, 29.21% with an average percentage of 43.84 for all sports. Finally, tennis players, when compared with athletes of other sports, least preferred a Republican Presidential candidate and had most frequently been previously divorced.

Webb (35) conducted a similar study in which the male graduates of a midwestern university who had played on the intercollegiate tennis team ranked sixth out of 11 sports on gross family income and third on fathers' occupational status. A study (19) of an eastern university's intercollegiate tennis players who graduated from 1900 to 1960 revealed that they most frequently entered the fields of medicine, engineering and law and had least often taken up dentistry or management positions.

While these studies generally support the idea that tennis players come from an above-average social class and tend to pursue professional careers, some caution should be used before interpreting the findings too broadly. For example, the amount of social mobility achieved by athletes in a certain sport may not have been directly due to athletic participation. One must also consider the influence of a college education on social mobility. Furthermore, all athletes do not graduate from college; therefore studies that sought responses from only those athletes who had obtained a degree could reveal findings that were different. Finally, such investigations may have been affected by factors such as inadequate return of questionnaires, improper testing methods, regional biases, type of statistical treatment and other problems that plague the findings from these types of studies.

In spite of these findings, however, a number of American players who have ranked consistently in the top ten[2] (33) did not come from the well-to-do social classes. Typical examples include Stan Smith, Cliff Richey, Billie Jean King and Nancy Richey Gunter. The same also can be said about some foreign players. While there was no reported research on this point dealing with advanced tennis players, there was a meager amount of information on social origin and

[2] By the United States Lawn Tennis Association for most of the years from 1968 through 1972

competitiveness of normal populations. In part, these studies showed that individuals from both low and high class social groups tended to be less competitive (1). The lower class person believed that the odds were stacked too highly against him while the upper class individual saw a secure social position no matter what the outcome of the contest. Generally speaking, the best competitors come from the middle class groups (7). Perhaps it can be hypothesized that most tennis *players* come from the above-average social group, but most tennis *champions* come from the middle class group.

It has been argued (4) that the origins of competitive conflict lie in the oedipal competition between father and son. This was further substantiated by the fact that many tennis champions were identified with a father image (sometimes surrogate) for example, Ashe, Riessen, Cliff Richey, Nancy Richey Gunter and the Everts. In this regard, one is reminded of the influence of Harry Hopman with the Australian Davis Cup teams of the 1950s and 60s or Perry Jones and his control of southern California tennis. It has been suggested (4, 37) that the father-image phenomenon may result in an identity crisis, particularly with women players. Whether or not this is unique in tennis remains to be seen, for one could cite similar examples in other sports, particularly those which are individual in nature.

Finally, tennis is perhaps the only sport in which regular tournament competition is held for father-son and mother-daughter doubles teams. While it has been suggested (28) that the father has the greatest parental influence over the son, much more research is needed on the intricacies and implications of these familial relationships. It would be extremely difficult to separate father-son or mother-daughter influences due to inheritance from those influences that are primarily social.

PSYCHOLOGICAL CHARACTERISTICS

A review of the psychology of sport literature reveals an increasing amount of activity in the investigation of the personality traits of outstanding athletes. Historically, psychological studies have been criticized for lacking valid measuring tools from which reliable conclusions could be reached (14, 25). Recently, however, continued refinement of these tests, coupled with more reliable testing conditions, has made it possible to place more confidence in the results (14). In spite of these improvements, however, the few studies dealing with the psychological traits of competitive tennis players still revealed inconsistent and confusing conclusions. It is unclear whether these resulted from invalid measuring tools, different testing methods, inadequate sample sizes, different statistical treatments, regional biases, etc. (11, 14, 31).

INDIVIDUAL-TEAM SPORT PERSONALITY STUDIES[3]

It has been suggested that the personalities of individual sport athletes may differ from those of team sport athletes (14, 24). One investigator (7) theorized that individual sport athletes tended to be more withdrawn while team sport athletes tended to be more gregarious. It was not clear whether the alleged difference was the result of one's involvement in the sport or whether persons with specific personality traits originally chose an individual or team sport in which to participate.

The findings from some studies supported the hypothesis that a difference may exist between the personalities of individual and team sport athletes. Malumphy (23) found that midwestern intercollegiate women athletes from individual sport groups were less anxious, more venturesome, more extroverted and indicated more leadership than those from the team groups as measured by the Cattell Sixteen Factor Test of Personality. Conversely, team sport athletes were more reserved, more introverted and less venturesome than the individual sport athletes. In 1958, Booth (6) reported that intercollegiate male individual sport athletes showed significantly higher scores in psychasthenia (condition where individuals are subject to obsessions and phobias) and were more depression-prone than those in team sports as measured by the Minnesota Multiphasic Personality Inventory.

On the other hand, Lakie (18) found similar personalities for intercollegiate wrestling, basketball, football, golf, tennis and track groups as measured by the Omnibus Personality Inventory. Ikegami's study of some 1,500 male and female Japanese athletes who had competed in national athletic meetings did not reveal any marked differences in personality traits beyond individual and team sport athletes (12). While the findings from these studies represent only a limited sampling of what has been done in the area, they do give an indication of the type of inconsistencies that exist.

Specific Personality Traits

For clarification, the psychological studies dealing with competitive tennis players have been classified under that trait with which the investigation was primarily concerned. They are as follows:

Introversion-Extroversion

It was reported that marked tendencies toward extroversion were usually found when populations of superior athletes were tested (7). It was not evident whether this trait was the result of one's physical ability or was an innate characteristic.

[3] Only those studies that included tennis in the individual sport group are reported in this section.

Whatever the case with the superior athlete, extroversion probably does not typify the competitive tennis player's personality. Ogilvie (24) reported that top athletes were extroverted (particularly in team sports) with the exception of race car drivers, long-distance runners and male tennis players. Warburton and Kane supported that hypothesis when they wrote:

> Although in general extroversion goes with physical ability, many top "individual" athletes (i.e., track and field, swimming, tennis, etc.) are found not to be markedly extroverted and many world class performers are clearly introverts. (34)

Knapp (17) found no marked difference in the introversion-extroversion tendencies of 46 outstanding English tennis players (28 women and 18 men) as measured by the Maudsley Personality Inventory. However, a total of six players (three men and three women) scored more than one standard deviation above the English norm for introversion and three players scored approximately two standard deviations or higher on neuroticism when compared with the same norm. Knapp noted that coaches should take into account such divergent personalities when working with a team.

Ikegami's comprehensive study (12), which included 131 Japanese tennis players (71 men and 60 women), revealed that male tennis players were slightly more inclined toward extroversion than those from the following athletic groups: gymnastics, track and field, table tennis, basketball and volleyball. The female players barely exceeded all groups on extroversion except in the case of table tennis; however, all differences in the study were slight.

Olson (26) conducted a study in which tennis experts classified male players into groups of several skill levels including champions and "near-greats." Based on the rationale given by the experts for their rankings, an interview was carried out with 12 players representing each skill level. On the basis of these interviews, Olson concluded that champion players were most purposefully intense and serious, did not seem to be as aware of crowd reaction during a match and expressed "great-exhilaration" after a win and "deep-depression" after a loss. These traits were not as evident in "near-great" players. Olson generalized tentatively that champions may be extroverts, cautioning that more research was needed on the topic. In an older study, Gold (9) found that a limited sample of male intercollegiate and professional tennis players showed a more "extrovertive orientation of the thinking process" than did intercollegiate golfers.

Aggression

In various sports, particularly those in which physical contact is a part, controlled aggression is considered an important requisite. Probably because of the nature of the game, little research on the aggression of tennis players was reported. One psychiatrist (4) noted that the game was a paradox. On one hand

was the relatively sedate atmosphere of the match which was contrasted by the intense post-match language such as: "He killed me!" or "I murdered him!" Luszki (20) suggested that the successful tournament player is usually highly competitive and likely to be strongly sadistic while the player who emphasizes a noncompetitive game may be masochistic, apologetic and friendly. Roth and Puri (29) supported that suggestion when they found that the masochistic individual is usually less competitive than the sadistic person. Furthermore, the findings from their research revealed that male achievers tend to be extrapunitive (blaming others for their frustrations perhaps linesmen, ball-boys, opponents, etc.) while nonachievers tend to be intropunitive (turning hostile feelings toward themselves). This would support Olson's (26) conclusion that champion tennis players' aggressiveness was directed toward a recognizable external object while near-great players seemed to focus on something inside themselves not easily recognized by others. Singer (30) found that intercollegiate male tennis players were significantly higher in aggression than the norm group and lower on abasement (acceptance of blame, feeling of inferiority) than intercollegiate baseball players as measured by the Edwards Personal Preference Schedule. However, Singer's sample was small (10 tennis players) and the findings may have been influenced by a regional bias.

In contrast to those findings, Ostrow (27) reported no difference in the aggression level of intercollegiate male tennis players when compared with nonactive players and nonathletes. Furthermore, a season of competition did not affect the players' pre- through post-season frequency and total aggression levels as measured by the Edwards Personal Preference Schedule and six selected Thematic Apperception Test pictures.

It was suggested that competitive tennis players may have difficulty coping with their feelings of aggression. Whitman (36) hypothesized that some tennis players constantly berate themselves in order to balance their super-ego for being successful as well as providing punishment for failing. Beisser (4) cited instances of several world-caliber tennis players who constantly talk to themselves as the match progresses. This form of castigation supposedly is a method of avoiding guilt by denying that one is winning since most tournament players have unconscious destructive fantasies toward their opponents which interfere with the players' realization of the goal of winning (4).

Anxiety

It was reported (7) that either undue anxiety or complete freedom from worry can have a detrimental effect on the athlete's ability to perform successfully. Apparently, a moderate amount of anxiety in athletes is often an aid to superior performances (7). One older study, which will be reviewed later, indicated that anxiety levels may be greater in individual sports than in team

sports competition (8). Warburton and Kane (34) found world-class women players to have lower resting levels of anxiety than tournament-level women. Johnsgard and Ogilvie (13) reported that better tennis players scored significantly lower in anxiety and were found to be more self-confident and stable. Olson (26) noted that champion players did not feel the burden of "being expected to win" as much as the near-great players, which suggests a lower anxiety level on the part of the better players.

Gold (9) found that a small sample of male intercollegiate players showed a tendency to be more calm, unruffled and relaxed than professional players as measured by the Guilford-Martin Personality Inventory. Hammer (10) found no difference between anxiety and performance levels when tennis lettermen and nonlettermen were compared at the high school and junior college levels.

Intelligence

While intelligence may not be considered a personality trait, several measuring scales contained subtests which purportedly revealed an intelligence factor. While the research findings at this time do not reveal any definite conclusion with regard to the relationship between athletic ability and intelligence, it would appear that superior athletes, in general are average to above-average in intellect (7). Cratty (7) suggested that in those sports requiring a detailed mechanical analysis, the more intelligent athlete would be more likely to succeed. While tennis was not specifically mentioned, it could be classified in that category. Bell (5) concluded that high school girls selected to participate in district tennis tournaments had a slightly higher mental ability than those who were not selected as measured by the Otis Quick-Scoring Mental Ability Test. In slight contrast to this, Olson (26) concluded with "some significance" that near-great male players tended to be more concerned with so-called intellectual challenges or complex situations than did champion players.

Social Maturity

Several psychological tests measure a personality factor known variously as "sociability," "social inclination," etc. Tennis, a sport in which the social aspects of the game have always been evident, may attract more socially mature individuals or be responsible for the development of certain social traits more than some other individual sport activities. However, this cannot be documented. It was not clear whether competitive tennis players possess a greater social maturity than athletes in other sports.

At four western state colleges and universities Lakie (18) administered the Omnibus Personality Inventory to 230 intercollegiate male athletes, 38 of whom constituted a combined tennis-golf group. Within the state universities, tennis-

golfers had a higher average social maturity than the athletes of the other sports as well as a higher average social maturity than their counterparts at the state colleges. However, it should be pointed out that these data did not represent a "pure" tennis group.

Gold (9) found that male intercollegiate tennis athletes were more "socially-inclined" and "cheerfully optimistic" than the varsity golfers and test norm group at an eastern institution. Paradoxically, this author also noted that varsity tennis players lacked "social leadership" when compared with the test norm group. Olson (26) reported that champion players seemed to be less aware of crowd reaction during a match than near-great competitors which may suggest that top players have a lower social inclination.

Emotional Maturity or Self-Control

Some competitive tennis players are frequently chastised for their emotional outbursts while involved in match play. Such venting of emotions is usually magnified considerably when contrasted with the sedate atmosphere in which tennis matches are normally played. Tennis is unique in that, when an error occurs, play stops. Hence, the player is faced with nothing to do except contemplate his mistake. In many other sports, the erring athlete must immediately switch to defense, and play continues. This factor, along with the proximity of the spectators and the fact that the player is more visible, i.e., not obscured by special equipment such as a helmet and face mask, may contribute to the situation.

However, the scant amount of investigation on this topic indicated that champion tennis players may have a higher level of emotional stability than players of lesser ability. Kane and Callaghan (15) found world-class women tennis players to be more emotionally stable, self-confident and lower in frustration than players of lesser ability. Olson (26) supported this when he concluded that champions seldom appeared disturbed during a match while more poorly-skilled players seemed prone to allow their feelings to show. Malumphy (23) reported that intercollegiate women players were more emotionally stable than the control group.

Gold (9) revealed that varsity intercollegiate tennis players were "free from cycloid tendencies" (manic-depressive tendency) when compared with the norm group.

Masculinity-Femininity

Studies on this personality trait were too few and inconclusive to offer any definite findings. Bell (5) reported that high school girls in competitive tennis were no less feminine than the average girl in the study; however, girls who

reached the highest levels in tournament play exhibited more masculine traits as measured by the Guilford-Zimmerman Temperament Survey. Gold (9) concluded that male professional and intercollegiate tennis players were less masculine in their emotional and temperamental makeup than male professional golfers.

Conservatism-Liberalism

Because of the aristocratic heritage of the game, one might argue on the basis of empirical evidence that tennis players may tend to be more liberal in thought and action than athletes from other sport groups. Yet, there is not enough evidence to support this contention. One early study (32), which dealt with a limited sample, found intercollegiate male tennis players to be the most liberal of athletes representing several other sports. Lakie (18) found that male intercollegiate tennis-golfers had a lower average liberalism score than did basketball, football, track and wrestling groups.

Miscellaneous Personality Studies

The following studies revealed some findings on isolated personality traits of competitive tennis players.

Singer (30) used the Edwards Personal Preference Schedule to determine any possible personality differences among 59 male intercollegiate baseball players and 10 intercollegiate tennis players and a norm group of 760 persons. On 15 items, the tennis group scored significantly higher than both the baseball and the norm group on the following variables: achievement (doing one's best) and intraception (ability to analyze others). The tennis group also scored higher than the baseball group on dominance (leadership).

In the same study Singer also attempted to reveal any personality differences according to the tennis coach's ranking based on skill performance. The top five players were compared with the bottom five, and both groups were compared with the norm group. The top group was significantly greater than the norm group on achievement and order, while the bottom five players were significantly lower on order than the norm group. The findings may have been influenced by the small number and a regional bias.

One study (22) which reported on the aesthetic sensitivity of athletes concluded that competitive tennis players were not significantly aesthetically sensitive when compared with other athletic and control subjects.

SUMMARY

Based on the findings of the limited amount of sociological and psychological research on the competitive tennis player and keeping in mind the difficulties in

conducting such investigations, the author considers the following conclusions appropriate:

1. Tennis *players* tend to come from the above-average social class while tennis *champions* come from the middle class.
2. Successful competitive tennis players are more introverted and more extrapunitive with lower anxiety levels and higher emotional stability than players of lesser ability or norm groups.
3. Competitive tennis players appear to have difficulty handling their aggressive feelings.
4. The data were too limited and inconclusive to suggest conclusions on the social mobility, intelligence, social maturity, masculinity-femininity and conservatism-liberalism of the competitive tennis player.
5. More research needs to be conducted on familial relationships of competitive tennis players, i.e., father-image and family competition, as well as various psychological characteristics.

The sociological and psychological research on the competitive tennis player raised many more questions than it answered. Some of this undoubtedly is because of the nature of the research which carried with it the inherent spuriousness of analyzing social heritage and emotional makeup. More needs to be done for it may be that in this area will ultimately be found many of the answers that will prove to be most vital.

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2. PHYSICAL AND PHYSIOLOGICAL CHARACTERISTICS OF COMPETITIVE TENNIS PLAYERS

In previous publications of this type, considerable data were available for review in the area of physical and physiological characteristics of athletes, but for some unclear reason, the literature in this area is noticeably limited for competitive tennis players.

Perhaps one explanation may be related to the heritage of the game. With its aristocratic background and its association with a genteel environment, tennis players generally have not sought scientific information in the physiological realm. A second explanation may center around the recent development of interscholastic competition for both men and women (particularly at the public school level). This emerging situation may stimulate more research as coaches and players express a desire for such information, which heretofore has not generally been the case.

PHYSICAL CHARACTERISTICS

Body Structure and Anthropometry

It was assumed empirically that the body structure of competitive tennis players tended to be ectomorphic (slim, not heavily muscled) with some individuals classified as mesomorphs (muscular, athletic build). Of the male amateur American players who were ranked consistently in the top 10[1] (15), individuals such as Stan Smith and Arthur Ashe typify the ectomorphic description while Cliff Richey and Clark Graebner could be classified as

[1] Amateur rankings only for a majority of the years from 1968 through 1972 by the United States Lawn Tennis Association.

mesomorphs. However, the limited amount of data on the body structure of competitive tennis players did not permit any definite conclusion.

One of the most comprehensive studies in this area was done by Parton (12) who compared various motor ability, strength and structure measures of three male intercollegiate golf, tennis and volleyball teams. He found the mean body weight of a limited sample of 10 tennis players to be significantly greater than the golf team. However, the data represented a tennis team that averaged slightly over 6 ft-1¼ in in height and 184 lb in weight which, on the basis of empirical evidence, would not appear to be a representative sample. Olson (11) found that champion tennis players tended to be thin as youngsters, a trait not particularly evident in the "near-great" players; however, Malmisur (9) found no significant relationship between selected physical characteristics (among them height and weight) of 23 Junior Davis Cup players and their success in tennis.

An analysis of the USLTA rankings of the male players in the top 10 for a majority of the preceding five years ending with 1972 revealed an average of 6 ft in height and 169 lb in weight (15). Using the same criteria, women players averaged slightly over 5 ft 5½ in and 125 lb. The method of collecting these data was not given. Generally speaking, most competitive tennis players attempt to keep their weight as low as possible for their particular body build, without sacrificing endurance and strength.

Buskirk et al. (1) compared the external anthropometric and roentgenogram (X-ray) measurements between 7 nationally-ranked tennis players and 11 soldiers. They concluded that vigorous tennis playing may lead to an increase in the length of the radius and ulna in the dominant forearm. Furthermore, the tennis players' hand area, hand width, third finger length, wrist width and forearm circumference (relaxed and contracted) differed significantly between the dominant and other arm. Only hand width, wrist width and forearm circumference differ significantly among the soldiers' arms.

Parton (12) collected various structural measures of competitive tennis players. Among them were skinfold measurements (triceps, subscapular, suprailiac, calf), girth (biceps and calf), linear measures (standing height, arm length, forearm length, and hand length, lower extremity length, sitting height, leg length and tibiae length). It was found that tennis players in the study had significantly less hand length than the volleyball group and significantly greater leg length than the golf group.

Speed, Reaction Time and Body Quickness

The research generally supported the hypothesis that athletes have faster reaction times than nonathletes (5, 9, 14). According to the limited amount of research, competitive tennis players scored quite high on reaction times and body quickness when compared with other athletes. Jackson (5) found that

tennis players scored significantly better on the 10- and 30-ft dashes than did track and field, baseball and football players. Olson (11) found that "champion tennis players tended to be fast" as youngsters, a trait not evident in "nongreat" players. These findings were supported by Matzi (10) who reported the best response times were for tennis players over football players and nonathletes on hand, leg and combined hand and leg movements. Parton found intercollegiate male tennis players to be significantly faster than volleyball players in discrimination movements and choice hand-reaction time. Furthermore, Parton's analysis of the intrafactor correlations within the tennis group indicated there was no apparent relationship between hand-reaction times and total body movement times. However, Youngen (16) found that a small sample of female intercollegiate tennis players did not differ significantly in reaction time (interval between the excitation of a visual stimulus and the finger release of a reaction key) when compared with female intercollegiate swimmers, fencers and field hockey players. In the same study, tennis players were not significantly different in movement time (time taken to move the hand and arm a prescribed distance) than were the other athletic groups.

On the basis of cinematographical analysis, Plagenhoef (13) concluded that a fast-reacting male player standing in one spot required .37 sec to play a ball. If the player was forced to react quicker than this, it was impossible to return the shot. Talbert and Old (14) reported that in a hard-hitting exchange at the net, the players have about .20 sec to note the flight of the ball, determine the opponent's position, decide what to do and return the shot. In view of Plagenhoef's findings, this would be impossible; however, the factor of anticipation must be considered when discussing quickness and reaction time. Talbert and Old's data were presented with the understanding that keen anticipation is a necessity for success in competitive tennis. Certainly, quick reactions would be an advantage in topflight tennis, particularly in net play and on the service return.

Strength

Few studies were reported on the strength of competitive tennis players. Buskirk et al. (1) concluded that tennis playing leads to muscular hypertrophy in the dominant forearm. They found that muscle diameter measured at mid-ulna and grip strength differed between the arms of both tennis players and soldiers, but the differences were larger in tennis players. The ratio of muscle diameter to bone diameter at mid-ulna was larger between the arms of tennis players. Thus, considerable forearm muscular hypertrophy could be associated with participation in a vigorous unilateral activity. One may note empirically that the dominant forearms of many top competitive tennis players are hypertrophied.

Parton (12) collected nine different strength measures from intercollegiate male tennis players and compared the data with golf and volleyball team members representing the same population. A cable-tensiometer was used to secure shoulder flexion, elbow flexion, trunk flexion, trunk extension, hip extension, knee extension, wrist palmar flexion and ankle plantar flexion strength. A manuometer was used to determine the subjects' dominant hand grip strength on which the tennis team averaged 120.3 lb compared with 120 for the golf team and 118.2 for the volleyball group. The tennis group was significantly weaker in both hip and knee extension strength than the volleyball group. However, the tennis group was significantly stronger than the golf group in both wrist palmar flexion and ankle plantar flexion strength.

Flexibility

The only reported study on the flexibility of competitive players was done by Parton (12) who secured six flexibility measures from the tennis group identified earlier and compared them with the volleyball and golf teams. Flexibility data were collected on wrist flexion-extension, shoulder flexion-extension, trunk lateral flexion, trunk and hip flexion-extension, hip flexion-extension and trunk flexion-extension. The tennis team had a statistically significant smaller range of hip flexion-extension than did the volleyball team. No other significant differences were reported with regard to the tennis group.

Depth Perception and Spatial Adjustment

There have been a few attempts to determine the relationship between one's score on a depth perception or spatial adjustment test and tennis success. Normally, such investigations involved correlating some form of perceptive-type test scores with subjects who represented various levels of tennis skill.

Enberg (3) administered a tennis film test and the Witkin revision of the Gottschaldt Embedded Figures Test to 63 volunteer undergraduate women players who were classified as team players, beginning players and naive subjects. The subjects viewed a tennis film test constructed from movies taken of a player hitting forehand strokes toward the camera where the actual bounce location of the ball had been determined. After viewing three series of the stroke (series A: backswing six frames past the moment of contact, series B: backswing to the moment of contact and series C: backswing two frames prior to contact), the subjects were asked to predict on response sheets scaled to court size, the rectangle in which they believed the ball would have bounced. Three film sequences of the forehand stroke series were arranged: ABC, BCA and CAB. At the conclusion of the sequences, the subjects were asked to note any visual cues in making the decision about the ball bounce point. The scores were calculated

in deviation units from a zero point in the center of the rectangle of bounce location, with the most accurate predictions scoring zero. Hence, the lower the score, the more accurate the prediction. It was found that the team players were the least accurate (had higher scores) of the three groups in predicting the ball bounce after viewing a series, although a significant difference did not exist. A total of 45% of the team players had a tendency to predict that the ball would land farther into the court than it actually did, which compared with 33 and 30% for the beginning and naive groups respectively. The tendency to predict ball bounce forward of the actual location was less with 7.8% response for the team players and 15% for both beginning and naive players. The *r* between the Embedded Figures Test and the film test scores yielded .058. While about 15 items were mentioned for visual cues in predicting ball bounce point, the most common responses were related to the body, racket or ball.

Crow (2) performed a similar study in which 13 high skilled, 22 intermediate and 27 low skilled women tennis players were rated on their ability to compare the flight of a ball with where they expected the ball to bounce. Each subject in the high and intermediate groups underwent three testing sessions on alternate days for a week, while the low skilled group was tested on alternate days for two weeks. Reliability coefficients showed that test-retest reliabilities ranged from .99 to .83 for the three groups on the variables of depth judgment ability and lateral judgment ability. A two-way ANOVA showed no significant interaction time between depth and lateral judgment ability and tennis playing ability. A significant difference did exist, however, among the total groups' lateral deviation mean when compared with the total groups' depth deviation means. Finally, no significant differences among groups were found after an absolute deviation score was determined for each subject by using the Pythagorean theorem, and among-group differences were analyzed with a single ANOVA.

Kreiger (7) found that intermediate college men and women players were more proficient in tennis spatial adjustment than beginners; however, beginners showed a greater ability in figure-ground perception. Figure-ground perception was related to tennis spatial adjustment to a greater extent in more highly skilled players. Finally, men were significantly more proficient in spatial adjustment in tennis than women. It should be pointed out, however, that the study by Krieger did not include players of a highly skilled level; therefore, the conclusions are applicable only to beginning and intermediate players.

Physiological Characteristics

Stress Reactivity

Two studies were reported with regard to competitive tennis players in which the stress of competition was assessed through some physiological response. In

one such study, Krahenbuhl (6) attempted to determine the stress reactivity of six male intercollegiate tennis players through catecholamine excretions (urine analyses) at four levels of activity: basal, practice, competition anticipation and competitive situations. The catecholamines (adrenaline and noradrenaline) are affected by different degrees of physical or emotional activity (or the anticipation of such activity) and are known to influence either sympathetic nervous activity or the adrenal medullary secretion which can be determined by the amount of excreted catecholamines in the urine. Krahenbuhl found that the catecholamine levels were significantly greater during the competitive situation than at the other three levels tested. This indicated that the stress level of competition was higher than the basal, practice and competitive anticipation levels of the six players tested in the study.

A second study conducted by Farris (4) published in 1943 attempted to determine lymphocytic reaction (changes in the white blood cell count) on the basis of 300 blood counts of male intercollegiate wrestlers, track-men, baseball players, basketball players, golfers, crewmen, football players and tennis players taken before and after contests. It has been shown that "an abrupt increase or relative lymphocytosis can be produced in healthy persons within five minutes by certain emotional states such as anxiety, fear, anger and disappointment." In this extensive study, relative lymphocytosis remained about the same in tennis players until the completion of the match. It was also pointed out that a certain intensity in activity was essential to produce a marked leucocytosis in spite of the fact that some of the competition may have been prolonged as in tennis.

Aging and Tennis Success

The chronological age at which athletes achieve their most proficient performances has attracted some interest in various sports. The only reported study relative to this topic on competitive tennis players is somewhat antiquated, but may serve as an indicator. Lehman (8) secured the birthdates of the first winners or retainers of 317 French, British and United States tournaments from the late 1920s to the early 1930s and found that the average age was 27.63 years. Using similar criteria, the mean age for world champion boxers was 26.98, for professional baseball players (excluding pitchers), 29.07 and for English and American open golf champions, 31.01.

SUMMARY

A limited amount of scientific literature in this area made it difficult to establish any firm conclusions. The data on body structure and anthropometry, strength, flexibility, depth perception and spatial adjustment, stress reactivity and aging were either too meager or inconclusive to yield definite findings.

On the other hand, competitive tennis players in the reviewed studies generally scored better than other competitive athletes on measures of speed, reaction time and body quickness.

Future researchers interested in this phase of scientific investigation would do well to consider this area since a great deal more needs to be done. A challenge is issued to those who wish to respond.

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3. MECHANICS OF STROKE PRODUCTION

Strictly speaking, virtually every tennis player strokes the ball differently (11, 22). While most tournament players perform in a relatively orthodox manner, there have been some notable exceptions, such as Billy Johnson of the 1920s or the present-day French player, Francoise Durr. Apparently, playing styles are highly individualized. Several studies (2, 10, 21, 23), which will be reviewed later, indicated that considerable variation in mechanics existed from subject to subject, but that each individual showed extreme consistency in repeating the stroke.

While the experts were not in complete agreement as to what constituted perfect form, there seemed to be unanimity that a "range of correctness" existed within which most players should perform on most strokes if an exceptional level of skill was to be attained. It was generally agreed that ball control was the prime requisite for winning tennis (10, 18, 22) and any stroking style that could achieve that goal was normally considered acceptable. One source (7) observed empirically that the time to change a stroke was when it was no longer effective.

THE RACKET

Racket Weight and Balance

Knuttgen (12) investigated the effects of varying tennis racket dimensions on the stroke performances of 18 players, 9 of whom were advanced competitors. Racket length was important to the accuracy and general play of the advanced players, particularly when they were called upon to make rapid movements and adjustments in playing the ball with the longer 29-in racket. Predictably, advanced players were more accurate than beginning players with heavy rackets (13-5/8 oz). Racket proficiency appeared to be highly individualized. Plagenhoef

(18) suggested that most women players should use a strung racket that weighs 12.3 to 13 oz while a majority of men players should select one from 13 to 13.9 oz. In all likelihood, using a racket that is too heavy may contribute to a sore arm or tennis elbow. It was also reported (18) that racket size and weight measures do not always agree with the manufacturers' markings.

The racket balance or center of gravity must be a consideration in selection since this variable can affect the weight. A heavy-headed racket will feel heavier while a light-headed racket will feel lighter to the player. It was reported (18) that the racket will feel heavy if the balance point is beyond 13½ in from the end of the handle. The serious competitive player may be interested in determining the center of percussion which varies depending upon the racket balance and the location of the player's grip on the handle. If the ball hits the strings at the center of percussion, the force transmitted to the player's index finger is minimal (18). If the player's grip is with the butt end just outside the hand, most rackets are designed so that the center of percussion is in the middle of the strings. However, since both grip and racket balance fluctuate, the center of percussion also changes from player to player because the pivotal point changes upon impact. Data for computing a racket's center of gravity and center of percussion for each individual are given in Appendix A.

Racket Flexibility

The most comprehensive studies reported on tennis racket flexibility were conducted by Nash (14, 15, 16), who clamped frames to the edge of a table and attached 8.214 kg to the center of the unstrung head. By determining the centimeter drop of a light beam reflected on a screen from the attached frame, it was possible to measure the flexibility of the racket. The amount of racket exposed at the edge of the table was altered to determine three different flexibility scores: racket-head, racket-handle and throat, and racket-full length. Nash concluded that most metal rackets fell into the "very flexible" category while wooden rackets tended to range widely from a "very stiff" through the "very flexible" categories. Both Seetharaman (20) and Hegmann (6), who conducted similar studies, also found metal rackets to be more flexible.

Plagenhoef (18) reported a similar study on 25 rackets in which the heads were clamped solidly at the top and bottom, and the speed of a dropped tennis ball was calculated as it rebounded off the strings. It was found that the greater the racket flexibility, the less the force of the ball impact, which transmitted less force to the hand. Furthermore, the increase in time of impact lessened the speed of the ball thus making it easier to hold the racket firmly. On the basis of these findings, it was concluded that the tournament player may tend to use a less flexible frame in the hope of obtaining more ball speed. However, this may result in poorer ball control a vital factor in successful tennis play.

Racket Grips, Style and Size

The reported research on correct racket grips and size was noticeably lacking, and for good reason, since there is no unanimity among the tennis experts as to what constitutes the perfect grip. Furthermore, one can cite examples of almost every grip style and size among the world-class players. As was the case with stroking styles, perhaps the best solution to the dilemma is to recognize that there is a range of correctness within which most competitive players function in order to achieve success in high level competition. For the vast majority of players, this involves use of the Eastern or Continental grips or a variation thereof. The handle diameter one should select is a highly individualized decision. The literature contains many empirical suggestions on the most correct handle diameter with the most frequently-mentioned consideration in this regard being the player's hand size. Since most competitive players have established a particular grip style, the prospects of changing it should be given considerable thought, for such a task is formidable. Some of the criteria that should be considered in making such a decision would be the success of one's present play, one's competitive goals and the comfort or "feel" of the present grip.

It was suggested (18) that the most important factor in hitting a tennis ball is the firmness of the grip at the instant the ball impacts the strings. Apparently, this factor is as important as racket weight in obtaining ball velocity and results in what has been referred to as a "heavy ball." Some players are noted for stroking a heavy ball, which means that the ball velocity is greater than anticipated from the racket swing speed. On the basis of velocity studies on a limited sample of six rackets, it was concluded that such players utilize grip firmness at impact (18). No single racket seemed to be best in achieving ball velocity or grip firmness. The biggest variable in achieving ball velocity appeared to be grip firmness at impact.

Racket Stringing

Almost without exception, tournament tennis players prefer gut stringing because of its resiliency and better playing qualities. The type of stringing and the tension to which it is strung are among the factors that affect ball speed (12) and control (18). Pouzzner (19) concluded that 16-gauge gut strung at 50, 58 and 65 lb tension was more resilient than nylon and that both types of stringing were more resilient as the tension was reduced. Knuttgen (12) noted that gut stringing gave better results than nylon in the performance of general tennis skills.

Many competitive players, particularly at the high school and college levels, assume erroneously that the best stringing is the tightest one. While it was shown that a higher tension will give better results in ball velocity for advanced players (14), there will also be a resultant loss in ball control. The most suitable stringing

tension depends upon the individual's level of skill. Plagenhoef (18) recommended that one who plays regularly (no data were given for the competitive player) with a gut-strung racket of full head size should have the stringing done at 58 to 62 lb tension. This figure would be reduced if the racket head size were smaller or if nylon were used. The amount of tension one selects is also dependent upon one's style of play. The hard-hitting player who does not possess the necessary ball control may find improved accuracy with a reduction of 2 or 4 lb tension. Conversely, the player who strokes the ball very softly and possesses adequate accuracy may find that the pace will be improved by increasing string tension.

Plagenhoef (18) reported that when comparing rackets with string tensions of equal sound rather than equal string tension, the small-headed rackets had a slightly greater rebound at equal ball speeds. A smaller head required less stringing tension to obtain the same amount of string deflection as a larger head strung more tightly. On that basis, it was suggested that string tension be determined by musical note rather than by pounds of tension.

THE SERVICE

Practically every ranked male player and many top female players excel in at least two strokes, the service and the volley. With the exception of the European clay court circuit, virtually all major tournaments are played on some type of fast surface where the serve-volley game is essential for success. Furthermore, it was empirically observed (7) that an increasing number of players are using the attacking game on clay courts as well. For these reasons, plus greater photographic ease when compared with other strokes, several cinematographical analyses have been conducted on the service. It was generally agreed that there are three components of a good service: speed, spin and placement (10, 17, 24). Most studies on the service have been concerned with the speed and/or placement of the ball. Little scientific data were available on the spin of the served ball because of difficulties in securing accurate information.

Ball Toss

While the ball toss has been frequently regarded as one of the hallmarks of an effective service (10), surprisingly little data were reported on this phase of the service. According to Plagenhoef (18), the height of the toss and the drop of the ball prior to impact vary considerably among top players. Note Table 1 on the following page:

TABLE 1. HEIGHT OF THROW ABOVE THE CONTACT POINT AMONG SOME TOP TENNIS PLAYERS*

0 - 1"	Newcombe, Graebner, Talbert
1" - 3"	Seixas, Savitt, Palafox, Emerson, Osuna, Pilic
3" - 5"	Ashe
6" - 9"	Gonzales, Sedgeman, Hoad, Laver, Roche
9" - 12"	Kramer, Mulley, Richardson, Rose, Rosewall (1969)
12" - 15"	Stolle, Kalston, Smith, Santana, Connolly
15" - 20"	Smith, MacKay, Rosewall (1952)
20" - 24"	Lutz, Santana, Garcia, Drysdale, Barthe, Brough
24" - 30"	Chaffee

*Stanley Plagenhoef, *Fundamentals of Tennis*, 1970, p. 72. Reprinted by permission of Prentice-Hall, Englewood Cliffs, NJ.

Speed

While data on served ball speeds make interesting comparisons, it should be remembered that the fastest service is not always the best one. Speed is but one criterion for an effective service, and few players have the ability to serve the ball extremely hard *and* accurately for an entire match. It has generally been assumed that, when in his prime, the velocity of Pancho Gonzalez's served ball was the fastest in the game. Cooper and Glassow (4) reported his service measured electrically at 164 ft/sec (112 mph), while Talbert and Old (22) noted similar speeds for both Gonzalez and Tilden at 162 ft/sec (111 mph).[1] However, the fastest tennis service reported measured an alleged 154 mph (about 225 ft/sec) and was hit by Mike Sangster of England on June 6, 1963 (13). The ball was reported to be traveling 108 mph when it crossed the net. The type of measuring device and the manner in which the data were collected were not given.

No data were reported on served ball velocity for world-class women players. Intercollegiate women players have achieved a velocity of 100 ft/sec (68 mph) (4), although a surprisingly high velocity of 176 ft/sec (120 mph) for this group was noted (17). Fiereck (5) reported a service speed of 114.24 ft/sec (about 78 mph) for intercollegiate women players and indicated that a service velocity of 80 to 100 ft/sec (55 to 68 mph) could be considered a good speed for that group. There were several reports of top male and female players achieving service speeds considerably less than those indicated above; however, such scores probably represented a different type of delivery or less than maximum effort. Whatever the case, it should be noted that the top speed of a served tennis ball easily exceeds that reported for other sports, including golf and baseball (22).

[1] To put these data into perspective, a ball moving at 111 mph (162 ft/sec) would travel the entire length of a tennis court (78 ft) in slightly less than ½ sec (.48).

The data on served ball velocity presented thus far were collected with sophisticated timing and photographic equipment not normally available to most high school or college coaches. A few investigators (5, 8) attempted to determine served ball velocity by using a hand-held stopwatch; however, such measures have generally failed to discriminate between levels of ability. One investigator (8) constructed a service test which does not require special equipment and will estimate served ball velocity as well as indicate ball placement ability. Hewitt accomplished this by estimating the length of the first bounce of the served ball after it had passed beneath a 7-ft restraining rope above the net and landed in the receiver's right-hand service court. By dividing the receiver's service court into six areas (Figure 1), and separating the area in back of the service line into four zones (Figure 2), it was possible to calculate a value of one's serving ability, revealing both accuracy and ball velocity.

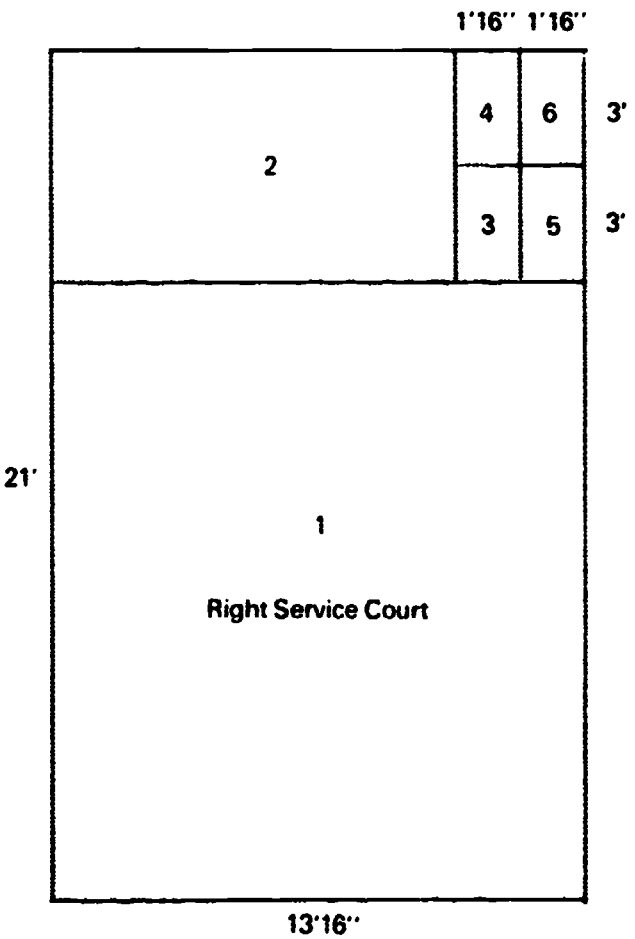

Figure 1. Hewitt Service Test. (Jack Hewitt, "Hewitt's Tennis Achievement Test," *Research Quarterly*, May 1966, p. 235. Reprinted by written permission of AAHPER.)

Apparently, the type of service (slice, American twist, etc.) had little effect on the length of the ball bounce. Hewitt reported that intercollegiate male players hit their services the hardest with the first bounce of the served ball landing 20 ft beyond the baseline. On a regulation court, this would be Zone 4 or the fence (Figure 2). A few male junior varsity and advanced players were able to hit their served balls on the first bounce to Zone 3. With a sample of 16 male intercollegiate junior varsity and varsity players, there were significant correlations of .93 between rank-order playing ability and service placement and .86 between rank-order playing ability and the distance of the first bounce. No data were reported on this test for competitive women players.

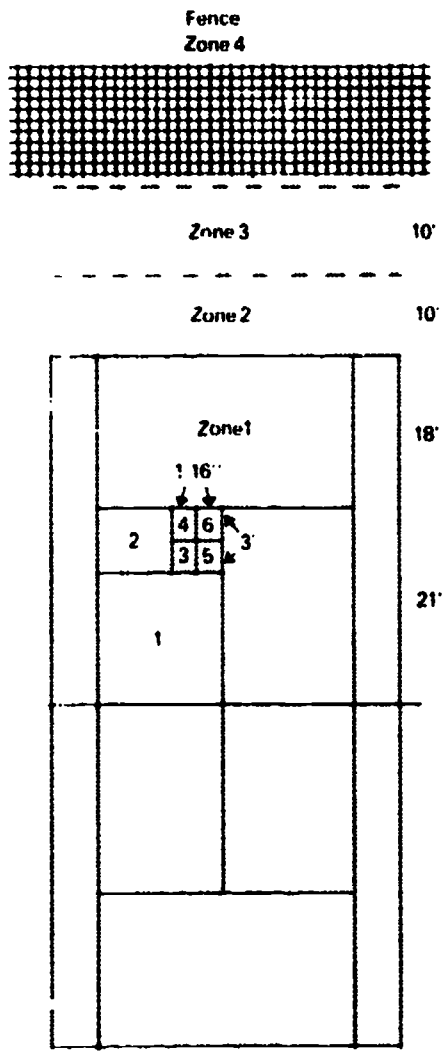

Figure 2. Speed of service distance ball bounces. (Jack Hewitt, "Hewitt's Tennis Achievement Test," *Research Quarterly*, May 1966, p. 237. Reprinted by written permission of the AAHPER.)

Spin

Few studies have determined the amount of spin imparted on the ball by the impact angle of the racket. Plagenhoef (18) reported that a right-handed player's American twist bounces more to the server's right and higher than the slice service. However, some of this variation (Figure 3) was due to the angle of approach to the bounce and the lesser amount of spin caused by deviation after the bounce.

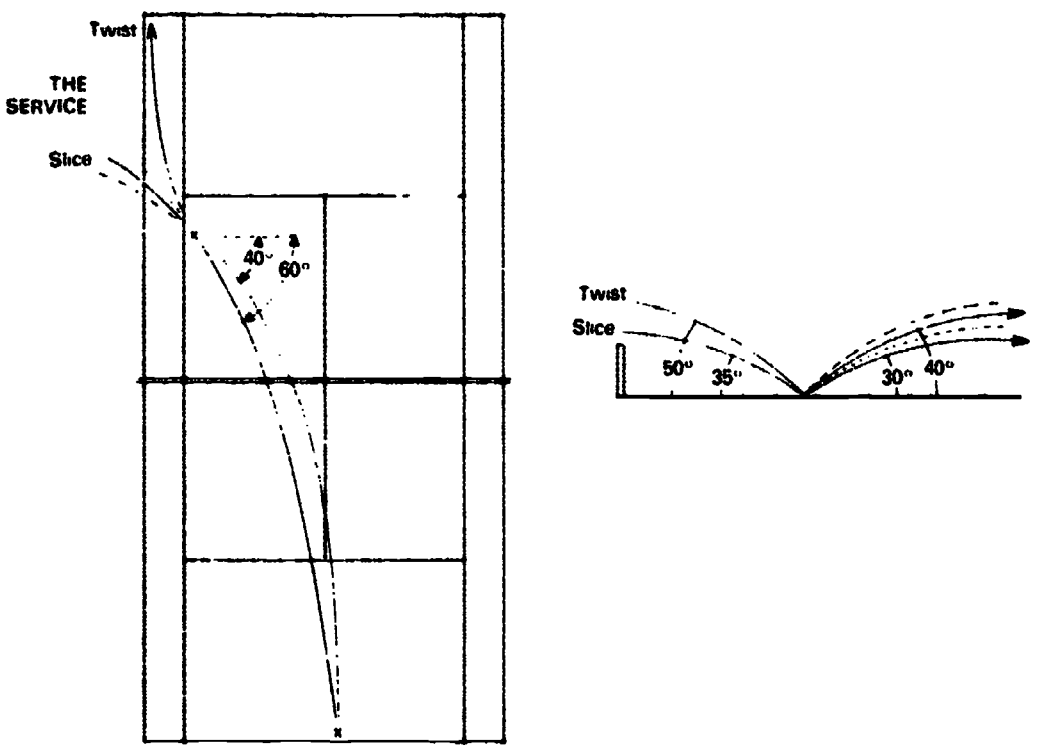

Figure 3. Ball spin - serve. (Stanley Plagenhoef, *Fundamentals of Tennis*, 1970, p. 78. Reprinted by permission of Prentice-Hall, Englewood Cliffs, NJ.)

Through cinematographical analysis, it was determined that the slice service was usually hit at about 15° ; whereas the American twist service would require an angle of about 40° to 60° across the ball line of sight (18) (Figure 4). Woods (24) reported that the desired slice spin could be obtained by hitting the ball on the upper right quarter segment for the right-handed player (upper left segment for left-handed players).

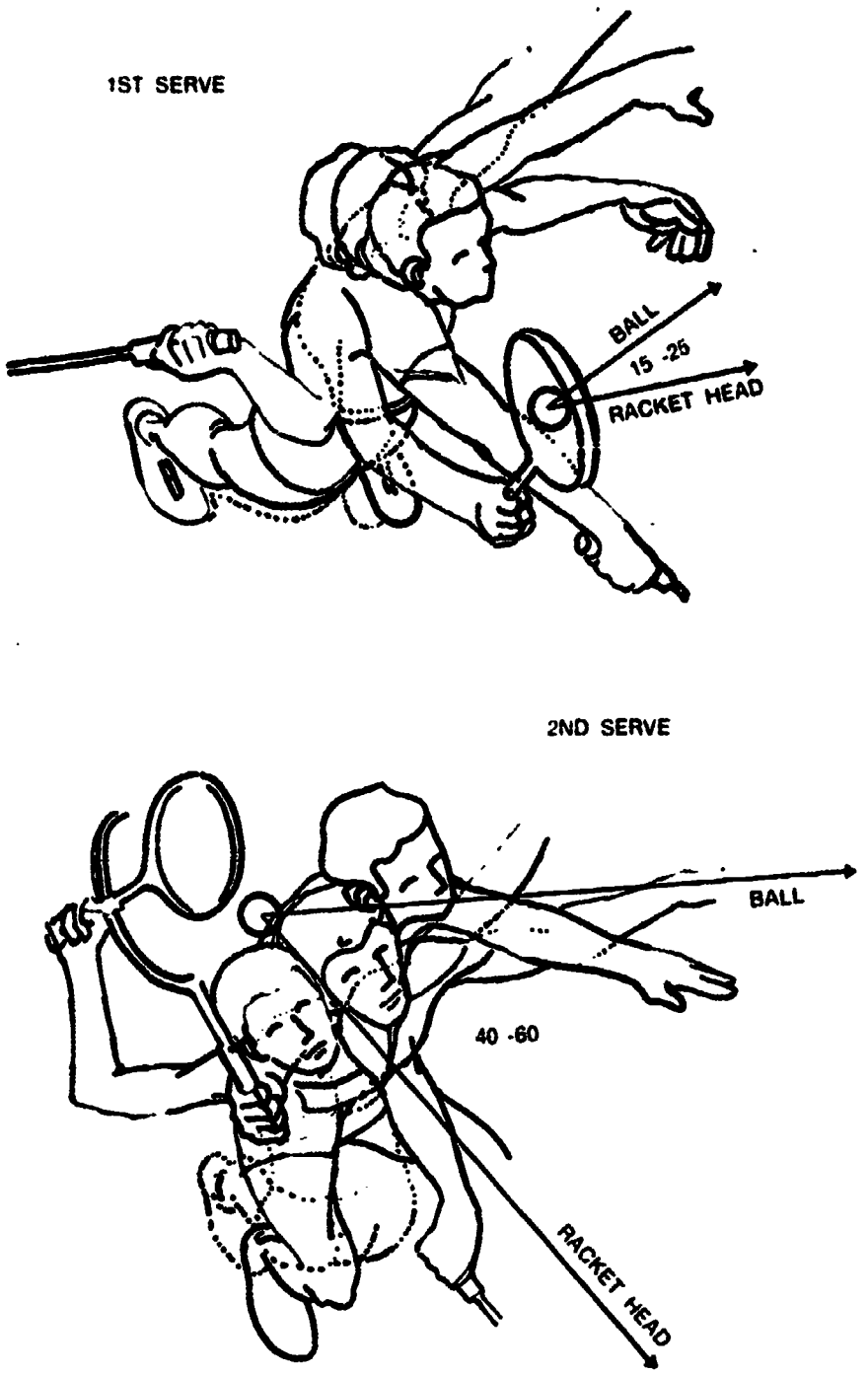

Figure 4. First and second serves. (Stanley Plagenhoef, *Fundamentals of Tennis*, 1970, p. 78. Reprinted by permission of Prentice-Hall, Englewood Cliffs, NJ.)

Some spin is essential in executing a high speed service; otherwise, it would be impossible to hit the ball into the service court. For example, a served ball traveling with no spin at 150 ft/sec (102 mph) from a point at the baseline 9 ft above the court at a downward 5° angle (excluding all environmental factors) would pass 4.52 ft above the court at the net and over 7 ft beyond the receiver's baseline (18). These data were selected since they were representative of the actual first service of a tall male player. While it is physically possible for only the tallest players to hit a truly "flat" service over the net and into the service court (3, 18), the margin of error would be so slight that the low percentage of placements would necessitate a different style of delivery. While air resistance and wind conditions may assist in adding the necessary drop to the ball, spin is the primary factor (18). In this regard, Owens and Lee (17) attempted to determine the velocities and angles of projection for the service. They reported that at high service heights and slower velocities, a ball can be hit as much as 8.47 ft above the court, cross the net 4.47 ft above the court and still remain in the service area.[2]

Data on service velocity, angles of impartation, etc., differ greatly since virtually every player hits the ball from a different toss standing at a slightly different angle to the court, etc. However, it may be concluded that the served ball must be delivered with some spin to get the ball into the service court and allow for the greatest margin of error. Thus, the true "flat" service is a misnomer.

It was reported (18) that both ball control and speed are dependent upon the firmness of the grip when the ball contacts the strings. By simply swinging the racket harder, ball velocity will probably not be increased and the resultant loss of body control may very well be detrimental to one's ball control. Assuming that striking mass was a variable dependent on grip firmness, a study (18) was conducted to show the relationship among ball speed, racket head velocity and the striking mass. Striking mass (how hard the ball hits the strings) was determined by measuring the point of impact on the strings both before and after impact. The ball velocity after impact was measured, and the striking mass was calculated using the formula:

Before Impact		*After Impact*
$mV + mV$	=	$mV' + mV$
ball racket		ball racket

By analyzing several services of world class players from slow-motion pictures (64 frames/sec, ¼ open shutter) in the plane of ball flight, it was concluded that

[2] However, in high-level competition, a served ball traveling that slowly would probably be ineffective.

the amount of racket head speed is no more important than the firmness of the grip. These data are presented in Figure 5.

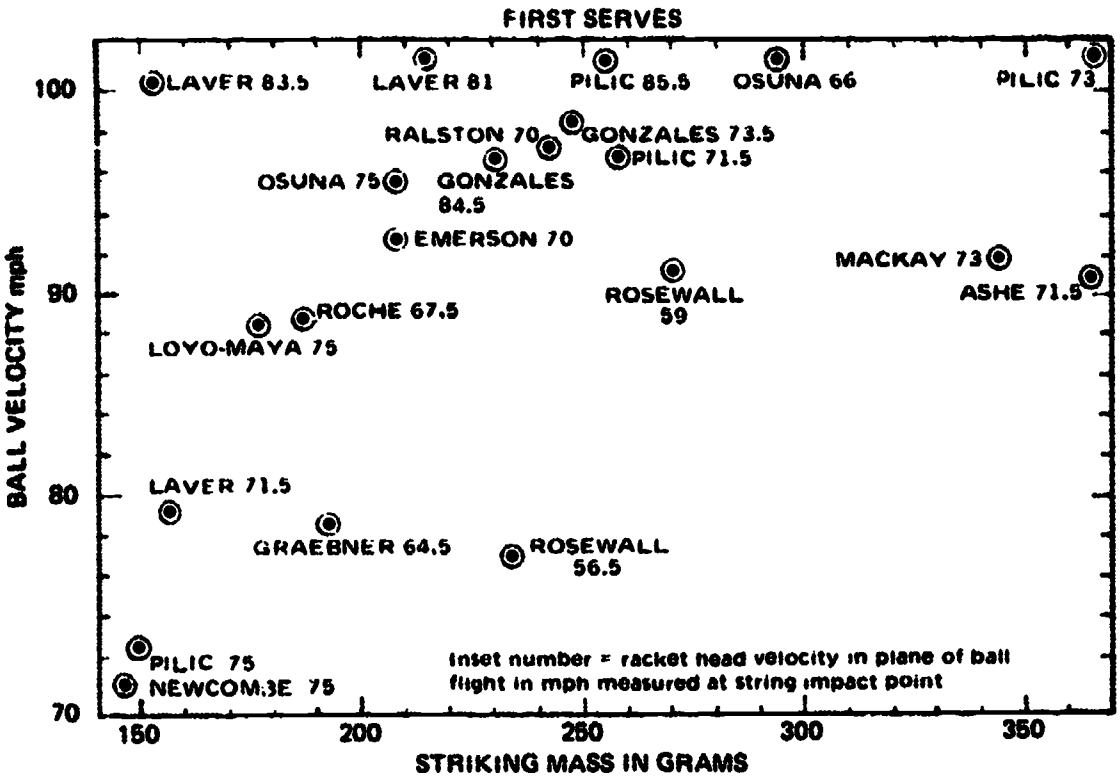

Figure 5. Ball velocity attained by numerous top players. (Stanley Plagenhoef, *Fundamentals of Tennis*, 1970, p. 87. Reprinted by permission of Prentice-Hall, Englewood Cliffs, NJ.)

On the basis of the data presented in Table 5, it was concluded that:

Newcombe had a racket head velocity equal to that of other players, but hit this particular serve 25 mph slower. Pilic hit two serves, which differed by almost 30 mph, with the same racket head speed. Ashe and Pilic showed more ball speed, owing to good grip rather than fast racket speed. Osuna hit one serve 5 mph faster than another of his serves, with a swing 9 mph slower. Gonzales hit one serve 2 mph faster than another serve, with a swing 11 mph slower. Rosewall had the slowest racket speed; Laver, Gonzales, and Pilic were able to obtain the fastest head speed. (18)

FOREHAND AND BACKHAND

The forehand has been the subject of considerable research perhaps because it is the "workhorse" tennis stroke. Anderson (1) conducted a simultaneous electromyographic (muscular activity) and cinematographic study of nine women players, three of whom were highly skilled. The highly skilled players

showed a consistency of muscle activity indicating a well-developed stroke pattern; however, there was great variation in muscle activity among the subjects. These findings were similar to Slater-Hammel's (21), who found in an earlier study with five "good" male tennis players that each subject's contraction movements were consistent but noted differences from subject to subject in timing and coordination. Johnson (10) reported similar findings in analyzing the services of advanced women players. These conclusions would support the hypothesis that stroking styles are highly individualized.

Blievernicht (2) performed a film analysis of the accuracy in the forehand drive using two right-handed male competitive tennis players as subjects. The study was delimited to an investigation of horizontal or right-left accuracy in which the subjects were requested to respond to an oral cue of "right" or "left" approximately 2 sec before the ball left a Ball-Boy machine. The cue word indicated to the subjects that they were to stroke the ball into a target area at the right or left corners of the doubles courts. Based on a number of anatomical measurements as well as racket angle and drive direction, it was concluded that the position of the ball with the relation of the body, the left foot direction, and the racket angle were all factors in directing the ball left or right. Step direction was a factor for one subject but not for the other. No one wrist angle or range of angles was associated with the drive direction. It appeared that all the joint actions involved in the tennis forehand seemed to contribute in movement to move the racket to the desired angle and position in space.

Young (25) compared selected mechanical factors (speed of racket movement, ball velocity, racket movement distance, shoulder angle, spinal rotation and pelvic rotation) and accuracy in the forehands and backhands of 15 novice and 15 advanced players. The strokes were filmed from both the side and overhead positions while accuracy was determined by ball placement in target areas on an outdoor court. Based on the film analysis and the accuracy scores, the following conclusions appeared salient for the subjects in the study:

1. Both novice and advanced players were similar in the performance of the forehand in the distance the racket moved on the forward swing, shoulder position, player's distance from the ball, knee flexion, spinal rotation and pelvic rotation.
2. The similarities of both groups in the performance of the backhand were racket movement time on the forward swing, distance the racket moved on the forward swing, shoulder position and spinal rotation.
3. The advanced players' forehands were greater than those of the novice group on the following factors: ball velocity, player's distance from the ball, racket angle, pelvic rotation and accuracy.
4. Knee flexion on the backhand was greater among the novice players than among the advanced players.

5. An increase in ball velocity on the forehand was accompanied by an increase in the distance the racket moved on the forward swing of the advanced players.
6. An increase in ball velocity on the backhand was accompanied by an increase in spinal rotation of both groups.

Hobart (9) conducted a cinematographical analysis of the backhands of 11 male tennis players representing three levels of ability: unskilled, moderately skilled and highly skilled. While the study did involve a limited sample, some mechanical differences among the groups were noted. The unskilled group extended the right knee at complete backswing on the backhand more than the highly skilled group. Also, the highly skilled group exhibited more knee flexion than the other groups.

Tennis has been referred to as a ballistic-type activity, that is, it involves the propelling of a projectile in flight. However, there is some evidence that this may not be the case, particularly with regard to the forehand drive in skilled players. Both Anderson (1) and Slater-Hammel (21) concluded that the forehand was nonballistic, and they based their findings on the contraction incidence of the driving muscles. Slater-Hammel found that with one exception, the subjects' driving muscles commenced contractions at varying intervals after the start of the drive and generally continued into the follow-through. Anderson found a decrease in muscular activity rather than a complete absence of muscular tension. Furthermore, there did not appear to be direct relationship between increased velocity and greater decrease in muscular activity.

VOLLEY

The only reported study on the volley was by Turner (23) who divided the stroke into 20 body and racket actions which covered getting into position, hitting and following through. Five professional tennis instructors were then interviewed concerning the mechanical, anatomical and quantitative aspects of the volley. They agreed that power came from the legs thrusting the body forward, turning the shoulders, and either extending the elbow or swinging the arm from the shoulder. They favored the Eastern forehand and backhand grips but did not agree on one perfect volley style.

SUMMARY

On the basis of the limited findings, it appears that there is a mechanical "range of correctness" within which the competitive tennis player should perform. The experts were not in agreement as to what constituted the ideal mechanical form and style of play. The selection of a suitable racket and the gut

tension appeared to be a highly individualized decision based upon various factors.

Relatively little research has been conducted on the various tennis strokes. However, it would appear that the following points are reasonable based on the research findings: 1) the true flat service is a misnomer since some spin is essential to get the ball into the service court; 2) the height of the service toss varies considerably among top players; 3) grip firmness is important to both ball control and speed; and 4) there is considerable variation from player to player on the various ground strokes, but there is a high level of mechanical consistency on successive strokes by the same player.

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4. ORGANIZATION AND ADMINISTRATION FOR INTERSCHOOL COMPETITION

General Consic vations

Both interscholastic and intercollegiate tennis competition in this country have been characterized by a lack of consistency in their patterns of organization. For example, the number of singles matches that constitute a regulation lineup may vary from four to six players or more. In some states, high school players are limited to competing in singles *or* doubles (this rule does afford an opportunity for more people to be involved in the program). Occasionally, confusion and hard feelings may result from problems such as different methods of exchanging lineups, varying methods of scoring and substituting in the doubles lineup after a player has been injured in a singles match. These situations sometimes have been compounded by the fact that beginning tennis coaches have been ill-equipped to assume their responsibilities. In too many cases, such individuals were forced to draw on experiences from coaching other sports (if any), and were at the same time faced with the task of learning to coach the game. This has led to a number of problems, including a high turnover rate of coaches, discouragement on the part of players, and sometimes a lack of continued enthusiasm and interest in the tennis program.

The only reported study which was concerned with these problems at the national level was done by LeFevre (17) who surveyed the membership of the Intercollegiate Tennis Coaches Association (ITCA) in order to compile a document which could serve as a guideline for the conduct of intercollegiate tennis competition. The results of this study (Appendix B) were adopted by the ICTA and now serve as a directive in governing intercollegiate competition. High school coaches will note that it is equally applicable to that level of competition as well.

In a similar survey, Schulman (23) found the average number of intercollegiate women players on a team to be 11.37 while the men's team averaged 10.13. The same study also revealed that quite a discrepancy existed between the number of matches played per season by men's and women's teams. According to the coaches who responded, the men averaged over 20 matches (20.83) while the women played an average of 8.7 matches per season.

Determining and Predicting Ability

The acquisition of valid and reliable predictive measures of athletic ability has proved to be one of the most frustrating areas of research. Understandably, there have been few attempts to identify criteria that might be useful in predicting the ability of the competitive tennis player. This type of information could be very helpful to the coach who is faced with the problem of determining the lineup prior to a season of competition and lacks the facilities and time to conduct extensive challenge play. With this in mind, Donnell (8) ranked eight advanced women players on the basis of two months of challenge competitions and found that the Broer-Miller Achievement Test correlated highest with the rank-order of the players ($r = .62$) and was the only test found significant when compared with the other tests and rank-order. The Kemp-Vincent Rally Test indicated a low correlation with the other skill tests and rank-order; whereas the Hewitt Revision of the Dyer Backboard Test correlated .59 with the Broer-Miller Achievement Test and .44 with the rank-order. Donnell concluded that the Broer-Miller Achievement Test was the single most effective measurement in the assessment of advanced tennis ability.

Hoth (12) attempted to determine if the basketball throw for distance, as administered in the Scott Motor Ability battery, was a valid predictive measure of tennis ability with 30 college-age women representing various levels of skill. By using the combined results of the Dyer Test, Broer-Miller Achievement Test and judges' rating, a composite score known as "tennis playing ability" was calculated. The correlation between tennis playing ability and the basketball throw was found to be statistically significant (.77). Intercorrelations showed the Dyer Test to be the least valid predictor of playing ability; however, it was effective in testing isolated qualities of an individual's ability to play tennis. When used in conjunction with the other two tests, its validity was relatively high. Hoth also noted that varying degrees of motivation may have caused discrepancies in the basketball throwing scores and tennis playing ability. Individuals who have a great desire to improve themselves stand a greater likelihood of success despite average predictive scores. This factor poses still another obstacle for the investigator attempting to predict athletic ability.

And finally, Malmisur (19) found that ability rating by experts using the criteria of mobility, form functional strength, concentration, motivation and

tennis ability was an excellent indicator of tennis success in a study of 23 Junior Davis Cup players.

Practicing for Competitive Play

The way the tennis coach conducts practice sessions is vital to improvement of the competitive player's game. Traditionally, too many coaches have been guilty of permitting practices to be little more than warm-up and practice match periods. Little opportunity has been provided for the player to work on the weak points of his game or to practice a new strategy without the pressure of a match.

To conduct more effective practices, the coach must be aware of some of the basic principles of learning. For example, the length and placement of rest periods can affect the athlete's motivation (30). Frequently, zealous coaches believe that their squads need to practice daily a great deal in order to prepare for competition. Yet, the research findings indicated that distributed practice sessions (adequate rest between practices) showed more improvement in learning than mass practice sessions (little or no rest between practices) (5). For mass practices to promote learning over a period of time, the athlete must be highly motivated. Ideally, such motivation should be intrinsic in origin for the greatest amount of improvement to occur. Normally, extrinsic motivation (such as urging by the coach or material rewards) is relatively temporary as a motivational device (6).

However, the coach must consider individual differences in this regard. Some athletes flourish under a mass practice schedule while others profit from a distributed practice plan. Because of the nature of tennis and the smaller number of players with whom the coach is normally involved such individual differences can and should be accommodated.

To motivate the competitive player as much as possible, practice sessions should be as flexible and ever-changing as possible (5). While the player can be working toward the same goal (such as improving the second service or the crosscourt backhand), the manner in which this learning is being effected should not be too routine. Walsh (30) suggested that the innovative coach might wish to establish some type of match situation to make practice sessions as functional as possible. For example, in working on the service and service return, one point might be awarded to the server for each point won, while ½ point would be given to the receiver for each point earned. After a total of 7 points, the players reverse roles. This concept has innumerable applications. However, care must be taken to keep the players from becoming too competitive and neglecting the basic purpose of the practice. It was also suggested (5) that athletes in individual sports should be brought together by the coach and that individual goals should be known to the entire team. It was hypothesized (5) that in the individual

sports, feelings of teamwork will never take place unless such definitely planned techniques occur.

Research findings in mental practice indicated that groups requested to "think about" the activity between practice sessions showed significant improvement over those requested not to do so (34). Certainly, an important variable in mental practice is to determine exactly *what* the subjects thought about, and, if their thoughts were related to the activity, *how* did they think about it? Weiss (32) reported that mental practice was a definite asset in helping male high school players improve their game. However, very little scientific data were reported with regard to mental practice and its effect on improving the tennis skills of advanced players.

Conditioning for Competitive Play

When played well, most forms of athletic competition require not only a great deal of physical and mental conditioning, but also a high level of technical excellence. And competitive tennis is no exception since there are few more grueling athletic activities than a highly contested five-set singles match between two closely matched players. Talbert and Old (28) estimated that a player will stroke the ball approximately 1,000 times in the course of such a contest. Francis (9), after analyzing 12 singles and 7 doubles matches, concluded that highly-skilled men singles players ran an average of 1.15 mi per set of which 58.26% of the movement was traveled at "high speed" and 41.72% at "low speed." However, these data could vary depending upon factors such as length of the match, playing style, etc.

Yet, paradoxically, many competitive players typically do not engage regularly in a conditioning program except to play the game itself. The fact that this is the mode of conditioning practice may serve as substantial testimony to the rigor of high-level tennis competition. Frequently, the only occasion when many tennis players participate in some form of regular conditioning program is prior to some type of competition such as a schedule of interschool matches or the tournament circuit.

While there is a wealth of data available on the conditioning of athletes for interschool competition, little of it deals specifically with tennis players. Many conditioning programs suggested for competitive tennis players were empirically derived. Therefore, it may be necessary for the coach to become acquainted with the findings from scientific conditioning studies that will contribute to the development of those physical qualities deemed vital to successful high-level play.

It was generally agreed (18, 26, 29) that both speed (particularly over short distances) and endurance are two of the foremost physical qualities that the successful competitive tennis player must possess. Of these two factors, sprinting

speed is believed to be innate and therefore relatively fixed (3), while one's level of endurance can be improved comparatively easily.

It should be noted that there are two forms of endurance: muscular and circulatory-respiratory. The former is important to the competitive player since it permits him to engage in a large muscle activity for the duration of an extended match, i.e., serving for five sets. Circulatory-respiratory endurance is likewise vital since it involves the fitness of the heart and lungs and enables the competitor to run for the duration of a match. Since it is very difficult to predict accurately the length of a match, the serious player should prepare himself physically as much as possible for competition. Some form of distance running and/or interval training program would result in definite improvement in one's endurance (4).

It was reported earlier that body quickness and reaction time are also two qualities of many successful competitive tennis players; however, like speed, the extent to which these traits can be improved through training has not been substantiated.

In order to adhere to accepted principles of transfer, it is important that any conditioning program consist of activities that are specific to tennis. It has been shown that to achieve positive transfer, the two tasks must be highly similar (11). Therefore, if the coach feels strongly that the player should be in the "ready position" when not playing the ball, the conditioning drills should emphasize this. Or, if the coach wants to reinforce the concept of volleying the ball down, it would be useless (negative transfer) to have the player volley standing close to a wall where it is necessary to hit *up* in order to keep the ball in play.

Dobie (7) attempted to determine the effect of a conditioning program on selected tennis skills (service, forehand and backhand) and cardiovascular efficiency of 22 intercollegiate women tennis players at a northwestern university. The players were ranked and matched prior to the season by the Hewitt Tennis Achievement Test and placed randomly into control and experimental groups. Both at the beginning and end of the season, the groups were given a 3-min step test (Skubic-Hodgkins Cardiovascular Efficiency Test) to determine their cardiovascular efficiency. Both groups participated in regular tennis practices for the seven-week period, with the experimental group also performing twice a week in a continuous and strenuous 20-min conditioning program. This program consisted of progressing from level two to level five on the Adult Physical Fitness Program as prepared by the President's Council on Physical Fitness along with an agility run, a timed ball squeeze and a lunging exercise. Both groups showed significant improvement in cardiovascular efficiency at the end of the season but there was not a significant difference between them. It should be noted that according to the research on improving

cardiovascular efficiency, daily conditioning may have been more effective than performing only twice a week (2). Dobie found that the experimental group also improved significantly on both selected tennis skills as measured on the pretest and over the control group's posttest scores.

Walsh (29) suggested that a circuit training program (exercises at different activity stations) would increase the cardiorespiratory conditioning level of competitive tennis players. McKain (18) offered a similar program which emphasized endurance, speed and agility exercises while Pitchford and Hamilton (21) presented a system of isometric exercises to develop strength and power in tennis players.

Little has been done to determine specifically the effects of a weight training program on tennis performance. One study by Smith (26) investigated the effects of a weight training device on the off-season conditioning (particularly strength) of 30 high school female tennis players. Using two types of training devices, the Traditional Method (a 10-min running period and 15-min of wall rallying and serving) and the Device Method (Exer-Genie), the subjects trained three times weekly for 2½ months after which the groups switched the methods for the same length of time. Following the five-month training period, both groups practiced or played interschool matches daily for two months. Measurements of strength on the forehand, backhand, service and legs were taken at the start of the training period, before the switch in methods and prior to and following the tennis season. Smith found that "long-term strength gains" were more readily achieved by starting with the Traditional Method and then switching to the Device Method. By reversing the methods, "intermediate strength gains could be achieved." It was concluded that off-season training and conditioning were beneficial to high school female tennis players.

Injuries in Competitive Tennis

When compared with most vigorous athletic activities played at a high skill level, competitive tennis is relatively injury free. The main area of injury is in the musculo-skeletal system, most commonly involving tendons, ligaments and muscular strain. Generally, they are confined to the ankle, knee, shoulder, elbow, wrist and back. While a variety of injuries may affect these areas, in most cases a sound program of proper conditioning seemed to be the best preventive measure (16). In the case of injury, rest coupled with a medically-prescribed treatment program will best promote recovery (16). Joint injuries should receive immediate first aid in the form of elevation, application of ice bags and immobilization which should be followed by an X-ray in order to prescribe correct treatment (16).

One common injury associated with but not unique to the sport is "tennis elbow." This is a debilitating pain on the lateral epicondyle of the humerus

(bony prominence on the outside of the elbow). Normally, the injury may be described as a strain or overstretching of the supporting elbow structures (14). Tennis elbow is usually associated with the "club player" who mis-hits the ball using poor form which places abnormal strain on the dominant elbow. Incidence seemed to be more prevalent in players over 30 years of age (13). Consequently, the competitive tennis player may not be hampered significantly by this injury, although there are exceptions.

According to the research on tennis elbow, one or more of the following factors seemed to be responsible for its occurrence:

1. Sudden change to a heavy, stiffer racket or modification of the center of gravity in the racket (20)
2. Change to a racket with a higher gut tension (22)
3. A poor or nonexistent preseason conditioning program particularly with regard to increasing dominant forearm power and flexibility (14, 20)
4. Improper or poor technique in stroking the ball (20)
5. Lack of muscular development in the dominant elbow (22)

While the experts were not in complete agreement with regard to treating tennis elbow, the following factors were mentioned as beneficial in a majority of cases:

1. Use of icepacks within the first 24-48 hours after injury, followed by whirlpool treatments, and finally exercise in the final stages of recovery (14)
2. Decreased gut tension (55 lb or less) (22)
3. A switch to a lighter, more flexible racket (perhaps aluminum or steel) (20)
4. Exercise program designed to strengthen the muscles of the dominant forearm (14)
5. Modification of the manner in which one strokes the ball so as to utilize the shoulder muscles instead of the forearm as a power source (22)
6. Localized injection with a Novocain-type product and cortisone (14)
7. Use of casts which enforce rest but may create atrophy in the muscle mass and compound the problem (13)

In mild cases or after the acute symptoms have subsided, some players have felt relief by taking aspirin a few minutes prior to warming up (20). Since the backhand and backhand volley seemed to be responsible for a vast majority of tennis elbow difficulties, it is also important for the player to stroke only forehands for the first few minutes on the court (20). In extreme cases of tennis elbow, surgery was recommended (16). When all else fails, the only solution would be to give up the game (20).

A number of devices are on the market under various brand names which consist of a band or strap that encircles the dominant forearm just below the

elbow. Apparently, they offer some relief to some players by either absorbing or altering the shock to the elbow when a player strokes the ball (20). However, research data were not available on these devices.

Heat exhaustion can be a problem in competitive tennis if certain precautions are not taken. It is usually caused by lack of salt and water in the body due to vigorous competition by a poorly conditioned or unacclimatized player. Symptoms may include headache, spots before the eyes, weakness and feeling dizzy, chilly or nauseous (16, 25). Treatment consists of immediate rest, preferably reclining with feet elevated, loosening tight clothing, cooling the body, and sipping water (16, 25). Proper conditioning, accompanied with adequate salt and water prior to and during competition, appeared to be the best preventive measure (25).

Determining the Singles Lineup

For purposes of interschool competition, the tennis coach is obliged to arrange the singles lineup with the best player at the #1 position, the second best player at #2, and so on. While there are a number of ways in which this can be determined, the usual mode consists of having the team candidates participate in a round-robin tournament. Armed with the results of that play, and considering factors such as experience, competitiveness, etc., the coach can then determine the order of play. Frequently, due to factors such as lack of time and facilities which limit challenge play, it is desirable to secure more data on the players' physical and psychological abilities to perform in a competitive situation. Certainly, the acquisition of more information could result in a more valid determination of the lineup.

Walsh (31) recommended revising the Dyer Backboard Test for male intercollegiate players in order to establish a challenge ladder. Some of the changes included a 7-9 ft restraining line from which the player volleyed consecutively and a 32-40 ft restraining line from which the player rallied the ball on one bounce. Valid results were reported when determined empirically, provided numerous trials were given over a five-day period.

The author achieved moderately valid results (.80) when compared with the results of round-robin play by having the squad rank all players on the team except themselves. By summing the ranks of all players, the individual with the smallest total became #1, the next smallest total #2, and so on. The criterion used for ranking was to arrange the squad in descending order on their ability to perform successfully in an intercollegiate match.

Determining the Doubles Lineup

Tennis coaches generally agree that the best singles players do not necessarily make the best doubles partners. Historically, many of the best singles players in

the game were not outstanding in doubles. While this may be partially because of the greater popularity that singles champions have enjoyed, a related factor also may be involved. Whitman (33) suggested that singles is the peak of expression in sport of the adversary system, which may explain why doubles has not always appealed to the younger competitive player.

The hypothesis that the best singles player will not necessarily perform as the best doubles partner was supported by Comrey and Deskin (1) when they reported that the ability to integrate and anticipate one's movements and actions with one's partner is somewhat independent of the ability to perform alone. While there is a moderate relationship between individual and group performance at high level ability, the coach should develop doubles teams whose members perform best as a pair, and not be too influenced by one's individual playing ability (6). Individuals who work well together, know their teammate's unique characteristics and accommodate well to each other's particular action patterns can make a good doubles team (5). The best doubles teams in history were formed by combining a steady tactical player whose finesse maneuvered the opposition into weak returns with a smashing player who could put the ball away (27). It was further suggested (27) that offense, teamwork, anticipation and concentration were most important in topflight doubles play. It was estimated that teamwork is approximately 25% of the game; therefore, if at all possible, doubles teams should be made up of players who like and respect each other (27).

In the selection of singles and doubles lineups, the coach also needs to consider psychological factors. The competitiveness of a player, the ability to withstand a stressful playing situation, etc., are all important contributory factors in determining how well a player will perform in such a situation. Therefore, the coach may want to consider administering some form of personality measure to the team to secure a more complete profile and accommodate individual differences. Such tests might include the Cattell 16 Personality Inventory, Edwards Personal Preference Scale, Eysenck Personality Inventory, Comrey Personality Scale, and Tutko and Ogilvie's Athletic Motivational Inventory. Coaches would need to seek the assistance of a competent psychologist to properly administer and evaluate the data of the results of some of these tests. The literature indicated that psychological testing is becoming increasingly prevalent with athletes.

Strategic Play in Singles

The literature was abundant with publications in which the authors devoted themselves at least partially to the strategies and tactics involved in playing successful competitive tennis. Unfortunately, however, the vast majority were based on empirical judgments and impressions and their inclusion in this research

monograph may be questionable. In spite of this, Harman's (10) book, while it must be categorized as an empirical work, has enjoyed a respected reputation among players and coaches due to its practical approach on strategy and tactics.

Perhaps the most comprehensive undertaking on scientific approaches to strategic play in tennis were the works by Talbert and Old (27, 28). These comprehensive publications consist of an exhaustive amount of data collected on championship matches which reveal frequency of stroke types, point-winning strokes, percentage of errors, etc. On the basis of these data, strategic guidelines were developed for both singles and doubles play. The singles guidelines are as follows:

1. Keep the ball in play, particularly on the service return and the first volley since 25% of each are errors.
2. Get the first service deep in play 80% of the time. Good players also get the second service in play deep in the court. Good first services, deep in the court, produce a won point about 75% of the time.
3. Aim services to the sidelines to open up the court; direct second services to the backhand.
4. On fast courts, follow every service rapidly to the net. On slow courts, follow the service to the net less frequently.
5. It is essential to develop an effective return of service. If you just get the ball back, you have almost an even chance of winning the point. If you can control the return, keep the ball low. Returns to the sidelines should result in a won point 40 to 50% of the time whereas returns down the middle will result in only about 20 to 30% won points and should be avoided.
6. The percentages favor the attacking player. By keeping the first volley within 8-10 ft of the baseline, the odds are 9-1 in favor of winning the point. A shallow volley, particularly in the middle of the court, will result in a lost point 6 to 7 times out of 10.
7. About seven out of eight baseline points are won soon after one of the players hits a short shot. (28)

Strategic Play in Doubles

The comprehensive work by Talbert and Old (27) which was referred to previously probably represents the most scientific approach to the strategic aspects of doubles play. The items listed below represent the compilation of data collected over a period of seven years at the National Doubles Championships at Longwood, at the Newport Casino Tournament and at professional matches. The most salient strategic and tactical features are listed as follows:

1. The service is used about 30% of the time and is responsible for 20% of all winning shots.

2. The server should get the first ball in play deep in the receiver's backhand service court at least 80% of the time. The server has almost twice as good a chance to win the point with a good first service as with a good second service.
3. The return of the service is the most difficult shot in doubles. The receiving team loses twice as many points as it wins on this shot.
4. In championship play, the odds are 7-1 against the receiving team achieving a service break.
5. The importance of net play cannot be overemphasized. Excluding the service and service return which must be played from the backcourt, one-third of all shots are volleys.
6. In doubles play, 80% of all points are won at the net position and 80% of all placements are won at the net position. Good doubles players have good volleys. (27)

Scoring Deviations

One of the problems in scoring tennis has been the inability to predict accurately the completion time of a match. Needless to say, this has created havoc with tournament directors and coaches in their efforts to conduct an efficient schedule of play. To alleviate this problem, numerous scoring deviations have been proposed. Perhaps one of the first was the Van Alen Simplified Scoring System (VASSS), which scores single points, as in table tennis, up to 31 points for game. Jarrett and Everett (15) compared the VASSS with the traditional method of scoring to determine the effects of time, endurance and scoring variables on the results of matches. It was found that there was not a significant difference in the mean match time between the two methods; however, the traditional method did result in a greater variability of match times. Neither scoring method had a significant effect on players' endurance. The matches in which the advanced players used the traditional method of scoring played a significantly greater number of points than the VASSS. It was concluded that using the VASSS resulted in a better control of time and match completion time and that won-loss results between the two systems were highly similar.

Schutz (24) proposed a mathematical model for evaluating and examining the accuracy (degree to which outcome is independent of chance) and efficiency (length of time to declare a winner) of various tennis scoring systems. Data were collected from the 1967 professional tennis tour of 14 matches (350 games) between Rod Laver and Andres Gimeno and applied to the model under the assumption that the "best" player was the one with the highest probability of winning a point. The scoring method which would most frequently result in the "best" player being declared the winner was ascertained. An indication of the

efficiency of the scoring system was found by analyzing the expected number of points that would be played in a match. The following scoring systems were evaluated: normal game, normal set, short set (6 games without the 2-game lead, i.e., 6-5 was a possible winning score), best of 3-set match, best of 5-set match, pro set to 10 games, pro set to 12 games, VASSS to 31, and best of 3 VASSS games.

The short set was found to be relatively inefficient with the pro set to 12 games having very little advantage over the pro set to 10 games. The normal set was much more efficient than either pro set model. The best of the five-set match, which required a large number of points in comparison to the best of three sets, was found to achieve little in efficiency. While Schutz did not reveal the most accurate and efficient scoring method as determined by the model, he did advise the application of the model to any proposed scoring systems.

Schulman (23) conducted a survey in 1971 of both male (N=48) and female (N=30) intercollegiate coaches across the country to determine the scoring trends at that level of competition. On the basis of the findings, the following conclusions were made:

1. The use of traditional scoring methods appeared to be on the wane, especially with regard to tournament play.
2. There seemed to be a consequent increase in the utilization of tie-breakers (both the 9-point and 12-point). Again this trend was more prominent in tournament competition.
3. In general, the women seemed to be more oriented toward traditional scoring methods than the men (23).

It appeared that female coaches preferred the 9-point tie-breaker while male coaches preferred the 12-point system. Schulman found that several factors were responsible for the diversity in scoring practices. Most significant of these were the need to impose a time limitation on matches, especially with regard to tournament play, and the increased spectator appeal due to shorter contests and the tension created by the tie-break.

SUMMARY

Interschool tennis competition has been characterized by a lack of consistency with a considerable amount of variance between men's and women's organizational patterns. It appeared that the Broer-Miller Achievement Test and possibly the basketball throw may be useful in predicting and determining the ability levels of competitive players.

Coaches should adhere to basic psychological principles of learning when planning and conducting practice sessions. Very little scientific data on mental practice and its effect on the competitive tennis player were reported.

Because of the strenuous nature of high-level tennis competition, conditioning was deemed vital for successful play at that level. However, there was not an overwhelming amount of evidence that a majority of competitive tennis players regularly engaged in a planned conditioning program. A planned program of distance running and/or interval training appeared to be the most beneficial in improving one's endurance, possibly the only physical trait (along with quickness and sprinting speed) that could be relatively easily improved.

Tennis elbow was the most popularly researched injury in the sport. A number of reasons were given for both the causes and treatments of the problem. The basic cause of injury appeared to be a lack of muscular development in the dominant arm with the basic treatment being rest from activity.

Little scientific information was available on determining the singles lineup. In establishing the doubles lineup, the coach should not be overly influenced by a player's singles ability, but rather by his ability to work well with a teammate.

Likewise, little scientific data were available on strategic play. Of all the advice given, the primary guideline for successful play appeared to be: Keep the ball in play

Several studies were reported relative to scoring deviations. When considering time involved, assurance that the "best" player would win, etc., it appeared that two out of three sets with some form of a tie-break was useful.

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5. NEED FOR ADDITIONAL RESEARCH ON THE COMPETITIVE TENNIS PLAYER

Throughout this monograph, the author has repeatedly pointed out the lack of scientific information available on the competitive tennis player. Perhaps the primary reason for this situation is related to the fact that, until recently, tennis has not enjoyed the widespread popularity that it now does. With this new growth, more interest will undoubtedly be generated in revealing some of the answers to questions that heretofore have been either ignored or justified on the basis of custom and tradition. Possible research areas might cover:

Sociological Characteristics

1. What effect does playing competitive tennis have on one's social mobility?
2. Do most competitive tennis players come from a specific social class?
3. What is the relationship between the competitive tennis player's familial relationships and that person's competitiveness?

Psychological Characteristics

1. Does tennis competition modify some aspects of a person's personality or do individuals with certain personality traits choose a sport such as tennis in which to compete?
2. How do competitive tennis players compare with other athletes (and the general population) on certain psychological traits such as introversion, aggression, anxiety, social and emotional maturity, masculinity, conservatism, etc.?
3. How does the intelligence of competitive tennis players compare with other athletes and the general population?

Physical and Physiological Characteristics

1. Is there a difference between the body types and anthropometry of competitive tennis players when compared with other athletes and the general population?
2. Limited research findings reveal that competitive tennis players scored better than other athletes on certain measures of speed, reaction time and body quickness. Were these qualities developed as a result of playing tennis or did individuals with those qualities originally "happen" to select tennis as a sport in which to compete?
3. How does the strength and flexibility of competitive tennis players compare with those of other athletes? Furthermore, what would be the effects of a planned weight training program on the competitive tennis player's game?
4. What is the relationship between the results on a depth perception or spatial adjustment test and the competitive tennis player's game?
5. What are the energy costs of high-level tennis competition?
6. What are the effects of various forms of tennis activity (e.g., practice, match competition) on players' stress reactivity? How does it compare with athletes in other sports?
7. At what age do competitive tennis players achieve their most proficient performances? How does this compare with other sports?

Mechanics

1. What is the most desirable mechanical "range of correctness" within which the competitive tennis player should execute the various strokes?
2. How may such factors as racket weight, balance, flexibility, and grip style affect the competitive tennis player's game? Can the scientific selection of equipment help to reduce injuries such as tennis elbow?
3. How does the type of racket stringing material and the tension to which it is strung affect the advanced player's game?
4. Considerable research has been conducted on the mechanics of the service; however, few studies have attempted to determine the amount of spin imparted on the served ball by the impact angle of the racket. The effect of ball spin on other selected strokes in the game would likewise be a worthy study.
5. The volley was cited as being vital for successful singles and doubles play. Yet, the importance of this stroke as a strategic weapon was not reflected in the amount of research performed on it. This is one stroke which needs to be analyzed further.

6. One study reported that grip firmness was an important factor in ball control and speed. More studies are needed to determine further the various aspects of this concept.

Organization and Administration

1. More studies need to be conducted to determine the most desirable organization pattern for interschool play (particularly intercollegiate). This would help alleviate some of the existing problems such as numbers of singles matches to be played, various rules interpretations, etc.
2. Studies to determine more valid and reliable predictive measures of tennis playing ability would be useful to players and coaches alike.
3. Further data are needed on the effects of mental practice in improving the competitive tennis player's performance.
4. Little scientific data are available on the most desirable conditioning programs for competitive tennis players. Studies in this area would be most beneficial.
5. What are the other methods of more accurately determining the singles and doubles lineups? Would data from items such as skill test measurements, peer rankings and psychological testing be helpful?
6. What are the most desirable strategic and tactical guidelines for singles and doubles competition? Can such guidelines be scientifically determined?
7. What is the most desirable type of scoring deviation? Considering all factors, which form of the tie-break would be most appropriate?

Additional Area

1. As of this writing, the history of intercollegiate tennis has not been reported as a research topic. Related historical studies such as the history of tennis in a high school, college, university, or conference could also be a justifiable topic. These historical areas are a mere fragment of what could be important studies by sport scholars.

The list above is not intended to be complete, for the possibilities are virtually endless. It is the author's hope, however, that the areas suggested might serve as an "idea ground" for those interested in research on the competitive tennis player.

APPENDIX A

CENTER OF PERCUSSION[1]

Mark the point on the handle where the palm just below the index finger touches the handle. Suspend the rack from this point and swing it in a small arc; measure the time of one full swing (over and back). This is done with a sweep second hand stopwatch, measuring the time of 10 swings and dividing by 10. The center of percussion is then found, using the following formula:

$$qr = k^2 \quad k^2 = I/m \quad I = t^2 mgr/4\pi^2$$

$$qr = t^2 mgr/4\pi^2 m \quad q = t^2 g/4\pi^2$$

$$q = t^2\ 32.2 \text{ X } 12/39.48 \text{ in from pivot point}$$

t = time
q = distance from pivot point to center of percussion
I = moment of inertia or irregular shape
m = mass
g = gravity
r = distance from pivot point to center of gravity
k = radius of gyration

If the period (t) were found to be 1.3 sec, the center of percussion would be 16.5 in from the swing point. If this point were 4 in from the end of the handle (as determined by your grip), the center of percussion would be 20.5 in from the handle end. Most racket head centers are about 21.5 in from the end, so this would indicate that the racket is either unsuited for you or you should move your grip slightly toward the head.

[1] Stanley Plagenhoef, *Fundamentals of Tennis*, 1970, p. 123. Reprinted by permission of Prentice-Hall, Englewood Cliffs, NJ.

APPENDIX B

RULES AND REGULATIONS TO GOVERN INTERCOLLEGIATE DUAL MATCH COMPETITION IN TENNIS[1]

General Recommendations

1. In order to standardize competition throughout the country it is recommended that team matches consist of six singles and three doubles matches.
2. The winner of a dual match shall be determined when a majority of individual matches has been won (i.e., five of nine).
3. Competing schools should employ written contracts for dual matches. These contracts should be initiated by the home team and should include all specified agreements and arrangements.
4. The home coach shall serve as referee.
5. Umpires or announcers for each match should be provided when possible.
6. The home coach shall be responsible for any necessary crowd control.
7. All matches shall be the best of three sets.
8. United States Lawn Tennis Association rules shall govern play except when such rules may be modified for dual matches as described herein.
9. Each team shall be accompanied by a bona fide institutional representative at all matches.
10. Players shall dress in appropriate tennis attire.
11. In the event of inclement weather, matches should be conducted indoors if suitable facilities are available.
12. The tie-break system to be used shall be the same as that adopted for the NCAA tournament.
13. Unfinished individual matches shall not count in any way as team scores.
14. The ball to be used shall be specified in the contract by the host school.

Facilities and Equipment

1. The host school shall provide for each match:
   a. Center net straps
   b. Singles sticks
   c. Scoreboard to display the running score for each court
   d. Team scoreboards
   e. USLTA approved balls
   f. Towels, water, first aid supplies and trainer services when possible
   g. Dressing facilities if requested by the visiting team.

[1] Reprinted by permission of John R. LeFevre, tennis coach, Southern Illinois University, who conducted the study.

Pre-Match Considerations

1. Coaches shall exchange both singles and doubles lineups simultaneously prior to the match.
   a. If the team match has been on in the singles, substitution of doubles teams may be made upon common agreement of the coaches.
   b. If a player is injured, ill or unable to compete in the doubles, another player may be substituted for him, the original order of play remaining the same.
2. All matches should begin promptly at the specified starting time. Individual matches may be delayed a predetermined period of time to accommodate a player late for legitimate reason.
3. Players shall be ranked in order of ability, the best player on the team playing at the number one position, the second best at number two, and so on through all the positions. This rule shall also apply to doubles play, with the strongest combination listed at number one doubles, and so on. The team appearing with insufficient number of players shall default matches at the bottom of the lineup, (i.e., the six-man team appearing with five players must default at the number six position, and in doubles, at the number three position.
4. Length of warm-up shall not exceed 10 minutes.
5. Each player shall be ready to start doubles competition within 15 minutes of the completion of his singles match.
6. Procedure to follow in the event of darkness or inclement weather should be reached between coaches prior to the start of the match.

During Play

1. Coaches may talk to players only when they change ends of court and shall not delay play by doing so.
2. Play shall be continuous as defined by the USLTA regulations.
3. Three tennis balls should be provided for each match. The balls must be changed at the end of the second set, or oftener upon prior agreement of coaches.
4. Either coach may request a footfault judge. It is the home coach's responsibility to make this assignment.
5. Ethical conduct of players and coaches shall be observed at all times. Use of profanity, obscene gestures or unsportsmanlike conduct shall subject the offending player to disqualification.
6. There shall be no rest period between second and third sets.

7. All warm-up serves shall be taken prior to the start of play.
8. A player may request interpretation of a rule of his coach or the host coach during play.

Post-Match Considerations

1. The host coach shall be responsible for reporting scores to the appropriate news media.